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TECHNICAL REPORT ARLCD-TR-81018

THE GIANT VIPER MINE CLEARING LINE CHARGE: CHARACTERIZATION OF ENERGETIC MATERIALS

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SEPTEMBER 1981

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report ARLCD-TR-81018
2. GOVT ACCESSION NO.: AD-A106 434
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): The Giant Viper Mine Clearing Line Charge: Characterization of Energetic Materials
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Louis Avrami; M.S. Kirshenbaum
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: ARRADCOM, LCWSL; Energetic Materials Division (DRDAR-LCE); Dover, NJ 07801
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: ARRADCOM, TSD; STINFO Div (DRDAR-TSS); Dover, NJ 07801
12. REPORT DATE: September 1981
13. NUMBER OF PAGES: 54
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Giant Viper	S.R. 371 pyrotechnic composition
Mine clearing charge	Interim qualification
PE-4 explosive	Composition analysis
PE-6/Al explosive	Blasting cap test
EU propellant	DTA/TGA

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Mandatory safety and characterization tests have been conducted on the following four energetic materials which are integral parts of the United Kingdom (UK) Giant Viper/Mine Clearing Line Charge. The materials tested were PE-4 Explosive (Booster), PE-6/Al Explosive (Main Charge), EU Propellant, and S.R. 371C Pyrotechnic Composition (Igniter).

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. KEY WORDS (cont)

Explosion temperature test
Electrostatic sensitivity
Friction sensitivity
Impact sensitivity
Small scale gap test
Large scale gap test
Detonation velocity
Burn rate measurement
Closed bomb measurement

20. ABSTRACT (cont)

The tests included composition analysis, blasting cap test, DTA/TGA, explosion temperature test, electrostatic sensitivity, friction sensitivity, impact sensitivity, small and large scale gap test, detonation velocity, closed bomb, and burning rate measurement.

In most instances, the test data agreed with the available data supplied by the UK. Most of the data show that the sensitivity of the explosive materials is between that of RDX and TNT.

Therefore, it can be concluded that when handled with the proper precautions and procedures, the UK energetic materials, PE-4, PE-6/Al, EU propellant, and SR 371C igniter composition, do not present any undue safety hazards. Interim qualification of these materials for US military use was, therefore, requested.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of Mrs. Irena Szkrybalo, Product Assurance Directorate, in this program.

SUMMARY

Mandatory safety and characterization tests have been conducted on the following four energetic materials which are integral parts of the United Kingdom (UK) Giant Viper/Mine Clearing Line Charge.

PE-4	Explosive	(Booster)
PE-6/Al	Explosive	(Main Charge)
EU	Propellant	
S.R. 371C	Pyrotechnic Composition	(Igniter)

The tests included composition analysis, blasting cap test, DTA/TGA, explosion temperature test, electrostatic sensitivity, friction sensitivity, impact sensitivity, small and large scale gap test, detonation velocity, closed bomb, and burning rate measurement.

The following results were obtained:

1. PE-4, PE-6/Al, and EU are all cap-sensitive.

2. In powdered form the EU propellant is much more sensitive than TNT (actually it falls between RDX and Comp B). However, in the large scale gap test where the EU propellant was in pellet form, the shock sensitivity value of EU propellant indicates that EU is less sensitive to shock than TNT.

3. All the materials passed the electrostatic and friction sensitivity tests with no reactions.

4. In most instances, the test data agreed with the available data supplied by the UK. Most of the data show that the sensitivity of the explosive materials is between that of RDX and TNT.

In view of the above, it can be concluded that when handled with the proper precautions and procedures, the UK energetic materials, PE-4, PE-6/Al, EU propellant, and SR 371C igniter composition, do not present any undue safety hazards. Interim qualification of these materials for US military use was, therefore, requested.

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BACKGROUND AND PURPOSE

The Giant Viper Antitank Mine Clearing Line Charge, L3A1C, is a trailer-mounted, rocket-projected, explosive-filled hose developed by the United Kingdom. This mine-clearing line charge system is being evaluated by the US Army Test and Evaluation Command (TECOM), Aberdeen Proving Ground, MD, for potential U.S. Army standardization under the International Material Evaluation (IME) Program.

TECOM required that, prior to any system testing, mandatory safety and performance tests be conducted on all the energetic materials (explosives, propellants, and pyrotechnics) associated with the Giant Viper. These tests are a prerequisite for the interim qualification of any energetic material considered for a military application.

A list was drawn up of 10 energetic materials which were in the system. Arrangements were also made to obtain the latest specifications, safety certificates, and characterization data from the UK. Since many of the tests and procedures conducted by the UK differ from those of the U.S., a relative comparison could not be readily made with any data of standard energetic materials used and tested by each country. Therefore, a decision was made to test the Giant Viper energetic materials with U.S. methods so that comparisons could be made with standard U.S. energetic materials.

As part of the system safety assessment of the UK Giant Viper the DARCOM Fuze Review Board convened on 3 May 1979 to determine if the fuzing system for that system complied with Military Specification MIL-STD-1316B, Safety Criteria for Fuze Design. The Board ruled that the fuze design was unsafe because MIL-STD-1316B prohibited the use of primary explosives [lead azide, lead styphnate, and aluminum (ASA)] and tetryl to be in line with the warhead line charge. A recommendation was made to redesign an out-of-line fuze.

The recommended action eliminated the need to test several of the energetic materials on the list for the Giant Viper (i.e., ASA, tetryl, gunpowder, etc). This reduced the list to the following four energetic materials:

PE-4	explosive (booster)
PE-6/Al	explosive (main charges)
EU	propellant
S.R. 371C	pyrotechnic composition (igniter)

TEST PROGRAM

The selected mandatory and characterization tests performed on the four energetic materials were in accordance with the Department of the Army Technical Bulletin 700-2 (TB700-2) (ref 1) and Volume IV Joint Service Safety and Performance Manual for Qualification of Explosives for Military Use (ref 2) (also known as the Triservice Explosives Qualification Manual, based on NAVORD OD-44811).

The following mandatory safety and characterization following tests were performed for the two explosives, PE-4 and PE-6/Al: Composition analysis, blasting cap, unconfined burning, thermal stability, vacuum stability, differential thermal analysis/thermogravimetric analysis, explosion temperature, electrostatic sensitivity, friction sensitivity, impact sensitivity, detonation velocity, and small scale gap test. An improvised modified bullet impact test was also performed on PE-6/Al explosive.

For the EU propellant the tests performed were the same as for the explosives but the small scale gap test and detonation velocity test were eliminated and the large scale gap test, propellant heat test, closed bomb test, and calorimetry data were substituted.

For the pyrotechnic composition S.R. 371C the tests performed were the same as for the explosives except that the burn rate measurement and calorimetry data were substituted for the small scale gap test and detonation velocity test. Also the blasting cap and unconfined burn tests were not conducted.

The test matrix for the Giant Viper energetic materials is shown in table 1.

Specifications were made available for each of the materials by the UK through the British Liaison Office, Ft. Belvoir, VA.

The PE-4 and PE-6/Al explosives were furnished in bulk form by the UK. One kilogram of PE-4 and approximately nine kilograms of PE-6/Al were shipped to ARRADCOM from the UK. A kilogram of EU propellant in a solid form was originally shipped. Subsequently, a 10.16 cm diameter billet which was disassembled from one of the rocket motors was made available.

The pyrotechnic composition S.R. 371C was not readily available, so a mixture was manufactured by the Energetic Materials Division, LCWSL, ARRADCOM, Dover, NJ, in accordance with the specification furnished.

For each of the materials comparisons were made with other common energetic materials tested under the same conditions. Also comparisons were made on a relative basis with data furnished by the UK.

TEST PROCEDURES

Each test procedure is described briefly and the reference for each is noted by its title.

Detonation (Blasting Cap) Test (TB 700-2, Chapter 3, Para 3-8)

In this test a 150 g sample was placed in a 100 mm beaker, 4.60 cm i.d. and 5.72 cm high, which was then set on a 10.16 x 10.16 x 0.95 cm steel witness plate. The sample was initited by an M-6 blasting cap perpendicular to and in contact with the top surface of the sample. The test was conducted a minimum of five times, or until a detonation occurred.

Unconfined Burning Test (TB 700-2, Chapter 3, Para 3-9)

A sample (approximately 130 g) was set in a container with sawdust saturated with no. 1 fuel oil. The sawdust was ignited by an electric match and the burning time of the sample was recorded.

Thermal Stability Test (TB 700-2, Chapter 3, para 3-10)

A sample was placed in a constant temperature explosion-proof oven at 343 K (75°C) for 48 hours. Any change in the sample was noted. The PE-4 and PE-6/Al explosive samples measured 3.81 cm cube. The EU propellant sample was a cylinder, 3.81 cm diameter, 5.06 cm long.

Vacuum Stability Test (Triservice Manual, Section 5, Para 5.5)

The vacuum stability test (VST) was conducted on a 5 g sample at 373 K (100°C) for 40 hours. The amount of gas evolved was determined.

Differential Thermal Analysis/Thermogravimetric Analysis

Simultaneous differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were obtained with the Mettler-2 Thermoanalyzer at a heating rate of 10 K/min in a static air atmosphere. For the S.R. 371C pyrotechnic composition, the DTA/TGA was also obtained in a nitrogen atmosphere.

Explosion Temperature Test (refs 6 through 9)

The test was conducted by immersing a copper blasting cap containing approximately 40 milligrams of sample in a confined state to a fixed depth in a molten metal bath. Time to explosion was determined by measuring the time required for the blasting cap to rupture. The immersion time was measured over the range of 0.5 to 10 seconds. The procedure is similar to that developed by Henkin and McGill (ref 6) and further modified by Zinn and Rogers (refs 7 through 9).

The data were utilized in a computer program to determine the apparent activation energy and the explosion temperatures for 1 second and 5 seconds. Only an apparent activation energy was determined since the sample was not subjected simultaneously to isothermal heating. The 5-second explosion temperature is the value usually reported in the literature.

Electrostatic Sensitivity Test (Triservice Manual, Section 5, Para 5.4)

An approaching electrode apparatus was used to determine whether the energetic material passed the electrostatic sensitivity requirement. The pass criteria for this test is that there shall be no reactions in 20 consecutive trials at the 0.25 joule energy level (0.02 microfarad capacitor charged to 5000 VDC).

Friction Sensitivity Test (Triservice Manual, Section 5, Para 5.3)

The friction sensitivity test was performed with the ARRADCOM (formerly called Picatinny Arsenal) friction pendulum apparatus (ref 11).

Impact Sensensitivity Test (Triservice Manual, Section 5, Para 5.1)

The ERL (NOL) type 12 impact hammer, utilizing a 2 1/2 kg dropweight (refs 2 and 11), was used to determine the impact sensitivity of the energetic materials. A full firing curve, as well as the drop heights corresponding to the 50% and 10° probability of initiation were obtained. The 10% firing point was also obtained using the ARRADCOM impact apparatus (ref 11). The firing curve was determined by the rundown method, using 20 trials at each height. The 50% initiation point was determined by means of the Bruceton up-and-down method. The 10% value was the minimum height which resulted in initiation of the sample in at least one of 10 trials.

Small Scale Gap Test (Triservice Manual, Section 6, Para 6.5)

The small scale gap test is used to evaluate the shock sensitivity of an energetic material. In this test, the standard donor explosive (Composition A-5) and the test material are pressed into identical thick wall brass cylinders, 2.54 cm (1.0 in.) i.d., by 0.5 cm (0.2 in.) i.d. by 3.8 cm (1 1/2 in.) long. The donor provides an explosive shock pressure which is transmitted and attenuated through a barrier of polymethyl methacrylate. By varying the barrier thickness (Bruceton up-and-down method), a thickness (gap) is determined which corresponds to a 50% probability of detonation of the test material. A decibang value is then calculated for each barrier thickness for comparison with other energetic materials since literature usually reports a decibang value. The decibang of a sample is calculated from the 50% barrier thickness as follows:

$$\text{decibangs} = 30 - 10 \log X$$

when X is the barrier thickness in mils.

Large Scale Gap Test (TB 700-2, Chapter 3, Para 3-12, Triservice Manual, Section 5, Para 5.2)

The large scale gap test is used to evaluate the shock sensitivity of an energetic material. In this test, the test material is loaded into steel pipes 4.76 cm (1.875 in.) o.d. 3.6 cm (1.44 in.) i.d., by 14 cm (5.5 in.) long. The donor consists of two pentolite pellets, each 5.08 cm (2 in.) in diameter by 2.54 cm (1 in.) long. The barrier (gap) consists of two types of spaces. The first are discs of cellulose acetate (called "cards"), 5.08 cm in diameter by 0.0254 cm (0.210 in.) thick. The second are cylinders of polymethyl methacrylate, 5.08 cm in diameter by 1.27 cm (0.50 in.) and 2.54 cm (1.0 in.) thick. Combinations of the spacers produce any desired gap in steps of 0.0254 cm. A modified Bruceton up-and-down method is used to determine the barrier thickness corresponding to the 50% probability of detonation.

Detonation Velocity Test (Triservice Manual, Section 5, Para 5.8)

The detonation velocity tests were conducted for the two explosives in steel tubes, 0.96 cm i.d. by 2.54 cm o.d. by 7.62 cm long (0.625 in. i.d. by 0.837 in. o.d. by 6 in. long) with 0.95 cm (0.375 in.) pin spacing. In addition, for the PE-6/Al explosive, the detonation velocity test was also conducted in steel tubes 1.59 cm (0.625 in.) i.d. by 2.13 cm (0.837 in.) o.d. by 15.24 cm (6 in.) long with the steel spacings at 1.905 cm (0.75 in.).

TEST RESULTS

PE-4 Explosive (Booster)

The UK specification for Plastic Explosive No. 4 (PE-4) is given in DEF STAN 07-10/2 (ref 3). The PE-4 consists of RDX uniformly coated with plasticizer in the form of a plastic (moldable) mass. (According to the specification, PE-4 should retain its properties over the temperature range 233 K (-40°C) to 348 K (75°C)). PE-4 is classified as a secondary high explosive in U.N. Classification 1.1, Serial No. 48, Compatibility Group D. The nominal composition is RDX/D29/PEDO - 88/11/1.

Composition Analysis (Triservice Manual, Section 6, Para 6.30)

The PE-4 explosive was analyzed as received. The results of the analysis were as follows:

Component	DEF STAN 07-10/2 Spec.	ARRADCOM composition analysis
RDX, Grade 1A %	88.0 ± 1	80.52
BP Paraffin/ Lithium Stearate, % (80/20 gelled to a grease) (DG29)	11.0 ± 1	18.33
Penta-erythritol Di-oleate, % (PEDO)	1.0 ± 0.3	1.15

The procedures used for RDX was Military Standard MIL-C-401C except that the paraffin-lithium stearate was extracted with 80/20 benzene saturated with RDX and absolute ethanol. The penta-erythritol di-oleate was extracted with warm water in a separate determination. The analysis procedures are accurate to ± 1%.

The results indicated that 5.5 to 9.5% less RDX and 5.3 to 9.3% more BP paraffin/lithium stearate were present in the PE-4 explosive than the amounts cited in the specification.

Detonation (Blasting Cap) Test

Only one trial was conducted on PE-4 since the first sample initiated high order. The resulting detonation blew a hole through the witness plate.

Cogan (ref 4) reported that PE-4 has been initiated by Engineer Special J-1 and J-2 electric blasting caps manufactured by Hercules; by No. 6 and No. 7 nonelectric Atlas blasting caps; by No. 6 electric by Hercules; and No. 8 electric by Atlas.

Unconfined Burning Test

The explosive burned brightly at the start and then settled to a steady burn for about 400 seconds until all the sample was consumed.

Thermal Stability Test

A PE-4 sample weighing 130 g was placed in an explosion-proof oven at 348 K (75°C) for 48 hours. After the allotted time, it was determined that the sample had lost 0.5 g in weight (0.4%) without any noticeable shift in color.

Vacuum Stability Test

The vacuum stability test (VST) was conducted on a 5 g sample at 373 K (100°C) for 40 hours. The amount of gas evolved was 0.47 mL/5g/40h. In a similar test conducted in the UK (ref 5) PE-4 produced 0.1 mL of gas from a 5 g sample after 40 hours at 393 K (120°C). Both values are well within acceptable limits.

Differential Thermal Analysis/Thermogravimetric Analysis

The DTA/TGA thermogram is shown in figure 1. The material underwent an endothermic reaction, followed by an exothermic one. The onset of the endotherm started at 468 K (198°C) and peaked at 473 K (200°C) which also was the start of the exotherm. The peak of the exotherm occurred at 493 K (220°C). The endotherm is attributed to the fusion of RDX.

The TGA trace indicated that the PE-4 started to lose weight slowly at 453 K (180°C). The weight loss became rapid at 473 K, and was completely consumed at 603 K (330°C).

Explosion Temperature Test

The explosion temperature data are plotted in figure 2. The data were utilized in a computer program to determine the apparent activation energy and the explosion temperatures for 1 second and 5 seconds. Only an apparent activation energy is determined since the explosive is not subjected simultaneously to isothermal heating. The results are listed in table 2. For comparison purposes the values for RDX, Comp B, TNT, and PETN are also listed in table 2.

Electrostatic Sensitivity Test

PE-4 complied with Triservice Manual requirements (ref 2) in the electrostatic sensitivity test in which no fires occurred in 20 consecutive tests at the 0.25 joule energy level. The test was conducted at a voltage of 5000 VDC and a capacitance of 0.02 microfarad. The relative humidity during the test was 64% and the ambient temperature was 293 K (20°C).

Jones, et al (ref 10) report that in the powder sensitiveness data for PE-4 (according to Safety Certificate No. 451) no ignitions occurred at 4.5 joules in the electric spark test.

Friction Sensitivity Test

The friction sensitivity test was performed with the ARRADCOM (formerly Picatinny Arsenal) friction pendulum apparatus (ref 11). The test produced no reactions in 10 trials using the steel shoe. The relative humidity during the test ranged from 54 to 62%.

Impact Sensitivity Test

The impact sensitivity data is plotted in figure 3. The 10% and the 50% firing point values are listed in table 3. Test data for other explosives are also listed in the table for comparative purposes. The results indicate that PE-4 is less sensitive than Comp B and TNT. The data agrees with the findings obtained in the UK using the Rotter impact machine.

The UK conducts impact sensitivity tests with the Rotter apparatus (ref 11) using a 5 kg dropweight. After obtaining the height at which 50% of the samples react using the Bruceton method, explosives are compared by a "figure of insensitiveness" (FI). The height for the sample is compared to the corresponding height for a standard explosive and multiplied by the FI of the standard. Therefore,

$$\frac{\text{median 50\% height of sample}}{\text{median 50\% height of standard}} \times \text{FI of standard} = \text{FI of sample}$$

The standard normally employed is a specially prepared RDX having an assigned FI of 80. The following FI's of the standard explosives are listed for comparison purposes (ref 12).

Energetic material	Median height (cm)	FI
PE-4	221	170
PE-6/Al	182	140 (ref 15)
EU	26	20
S.R. 371C	98	75
Lead Azide*	113	20
PETN	66	51
HMX	73	56
RDX	104	80
Comp B	152	117
TNT	197	152

*Tested with 2 kg weight; lead 2:4 dinitroresorcinate (standard), FI = 11, medium height = 61.

Small Scale Gap Test

In the small scale gap test for PE-4 the 50% gap was 0.411 cm (0.162 in.) which produced a 50% point decibang of 7.9. The 50% point decibang value for RDX is 4.35 and for TNT 6.0.

The UK High Explosives Data Manual (ref 10) reports a value for PE-4 of 1.625 mm for the gap test, RARDE scale. Comp B produced a value of 1.041 mm and TNT did not produce a measurable result (too insensitive).

Detonation Velocity Test

The detonation velocity test conducted on PE-4 were under confined conditions. In one test PE-4 was loaded into a 1.59 cm i.d. x 2.13 cm o.d. x 15.24 cm long (0.625 in. i.d. x 0.837 in. o.d. x 6 in. long) steel pipe with the pin spacings at 1.905 cm (0.75 in.). With a density of 1.6 mg/m^3 the detonation velocity was measured at 8218 m/s with a plate dent of 0.366 cm (0.140 in.).

In the second test the steel pipe was 0.96 cm i.d. x 2.54 cm o.d. x 7.64 cm long (.378 in. i.d. x 1.00 in. o.d. x 3 in. long) with the pin spacings at 0.95 cm (.375 in.). With density of 1.6 mg/m^3 the detonation velocity was measured at 8211 m/s with a plate dent of 0.307 cm (0.121 in.).

Cogan reported (ref 4) that PE-4 had a detonation velocity of 8222 m/s (26,974 fps) with a density of 1.61 mg/m^3. The PE-4 was a bare charge 2.54 cm (1 in.) square or cross-section and 17.78 cm (7 in.) long.

Additional tests were conducted on PE-4 by Cogan under different environments. A cold storage test was performed in which samples of PE-4 were placed in an environmental chamber and temperature cycled between 219 K (-54°C) (-65°F) and 242 K (-31°C) (-25°F) for a period of 10 days. The samples were permitted to equilibrate to ambient temperature before testing. The detonation velocity for these samples was 8450 m/s (27,724 fps). Similarly PE-4 samples were subjected at temperatures cycling between 319 K (46°C) (115°F) and 347 K (74°C) (165°F) for 10 days. These samples produced a detonation velocity of 8262 m/s (27,107 fps). In another test, samples of PE-4 were immersed for 48 hours in 3.048 (10 ft) of water. The samples gave a detonation velocity of 8276 m/s (27,151 fps) but with reduced steel-cutting power.

The UK obtained detonation velocities of 8210 m/s with a density of 1.61 mg/m^3 and a diameter of 2.54 cm (ref 10) and 8200 m/s with a working density of 1.56 to 1.58 mg/m^3 (ref 5).

Bullet Impact test (Triservice Manual, Section 6, Para 6.1)

The bullet impact test could not be conducted due to the small size furnished.

A very limited program was conducted with the PE-4 explosive obtained from the tail of the hose at the testing grounds at Twentynine Palms, California. In a single test the PE-4 sample was impacted by ball ammo using a steel backing. No effect was noted. In the other test a .50 caliber tracer round was used. Immediate burning occurred upon bullet impact.

Additional Data

The following PE-4 data is included for information purposes from Jones et al (ref 10):

Specific heat - 1.126 kJ $kg^{-1}K^{-1}$
Power - plate dent test - 90% of RDX at $\rho = 1.59$
Power - fragmentation - 90% of RDX
Heat of explosion - 5003 kJ kg^{-1} (1196 cal/g)
Volume of gas evolved (NTP) - 872 m^3 Mg^{-1}
Fuze test - failed to ignite
Trough test - ignites and supports train steadily throughout

Also Cogan (ref 4) reported that five specimens were subjected to a 30 caliber armor piercing bullet fired at a range of 30.48 m (100 ft). None of the charges burned. In the air gap sensitivity test, a gap of 3.81 cm (1.5 in.) was obtained.

PE-6/Al Explosive (Main Charge)

The UK specification for PE-6/Aluminum is given in Provisional Specification TS 595A. The PE-6/Al explosive consists of a uniform mixture of PE-4 explosive, plasticizer and aluminum powder. PE-6/Al is classified as a secondary high explosive in U.N. Classification 1.1, Serial No. 48, Compatibility Group D. The nominal composition is RDX/D929/PED)/Al - 72.2/11.9/0.9/15.

Composition Analysis (Triservice Manual, Section 6, Para 6.30)

The PE-6/Al was analyzed as received from the UK. The sample tested did not meet the specification. Samples were taken from the hoses used in tests at Twentynine Palms, California, and Yuma Proving Ground, Arizona, to determine if these met the specifications. The results of the analysis were as follows:

Component	UK spec 595A	ARRADCOM analysis	Twentynine Palms outer hose	Twentynine Palms inner hose	Yuma cold hose
RDX, %	72.3 ± 1.0	66.05	73.8	73.11	73.26
BP Paraffin/lithium stearate, %	11.9 ± 0.75	17.11	7.22	8.78	9.06
(80/20 gelled to a grease)(DG29) Penta-erythritol Di-oleate, % (PEDO)	0.9 max	0.85	0.81	0.9	.62
Aluminum, %	15.0 ± 1.0	15.99	17.67	17.21	17.06

The results indicate that, although the samples tested did not fall within the specification limits, the hose sample results were more in line with the specification. The aluminum was weighed by difference after removal of the RDX with acetone. The ARRADCOM sample result indicated that the RDX was about 6% less than the specification limit. The accuracy of the analyses procedures is ± 1.0%.

Detonation (Blasting Cap) Test

Only one trial was conducted since the first sample initiated high order. The resulting detonation blew a hole through the witness plate.

Unconfined Burning Test

A 134 g sample of PE-6/Al placed in a paper cup was set in a container with sawdust saturated with No. 1 fuel oil. From ignition of the electric match to burning, the time lapse was 129 seconds. The burn time of the PE-6/Al was 29 seconds. After burning the form of the sample remained intact.

Thermal Stability Test

A 3.81 cm cube of PE-6/Al weighing 131.0 g was placed in a vacuum oven at 348 K (75°C) for 48 hours. The post-test weight of the sample was 134.4 g. The 2.6% increase in weight cannot be explained. Prior to this test the sample felt moist and oily. After the heat test the sample felt dry to the touch. The sample appeared to be slightly lighter in color after the test.

Vacuum Stability Test

The amount of gas evolved from the PE-6/Al sample in the 373 K (100°C) environment was 0.37 mL/5g/40 h. In the UK (ref 5) a 5 g sample produced about 0.2 mL after 40 hours at 393 K (120°C).

Differential Thermal Analysis/Thermogravimetric Analysis

The DTA/TGA thermograms for PE-6/Al is shown in figure 4. The DTA trace of the onset of the endotherm was at 468 K (195°C) which is the fusion of RDX. The endotherm peaked at 473 K (200°C) which also was the start of the exotherm. The exotherm peaked at 493 K (220°C).

The TGA thermogram showed that this sample started to lose weight at 458 K (185°C). The weight loss became rapid at 473 K (200°C). At 543 K (270°C) the composition had lost approximately 82% of its original weight.

Explosion Temperature Test

The explosion temperature results are listed in table 2 and plotted in figure 5. The 5 second explosion temperature for PE-6/Al was 538 K (265°C). The information furnished from the UK (ref 15) indicates that PE-6/Al has an ignition point of 476 K (203°C). The tables also list the value for PETN, RDX, Comp B, TNT, and PE-4.

Electrostatic Sensitivity Test

The electrostatic sensitivity test was conducted at the same time and manner as PE-4. With PE-6/Al no fires occurred in 20 consecutive trials at the 0.25 joule energy level. The UK safety certificate data indicates that with the electrostatic spark PE-6/Al produced no ignitions at the 4.5 joule level (ref 15).

Friction Sensitivity Test

The friction sensitivity test was performed on PE-6/Al with the ARRADCOM friction pendulum apparatus. The test produced no reactions in 10 trials using the steel shoe. The relative humidity during the test ranged from 54 to 62%. The UK reports that PE-6/Al produced zero ignitions on all surfaces with the mallet friction test (ref 15).

Impact Sensitivity Test

A full rundown firing curve was conducted on the PE-6/Al explosive with the ERL (NOL) impact tester. Also the 50% Bruceton point and the 10% point were determined. The data are plotted in figure 6. The 10% point was also determined on the ARRADCOM impact tester. All the data are listed in table 3. Comparisons can be made with other explosives listed in the table.

A *Figure of Insensitiveness* for PE-6/Al is 140 (ref 15).

Small Scale Gap Test

The 50% gap was 0.363 cm (0.143 in.) which is equivalent to a decibang of 8.45. The 50% decibang value for RDX is 4.35 and for TNT 6.0.

The UK High Explosives Data Manual reports a value of 1.35 mm RARDE scale for the gap test (ref 5). For comparative purposes, Composition B is 1.041 mm. TNT does not produce a measurable result (too insensitive).

Detonation Velocity Test

Detonation velocity tests for PE-6/Al were conducted in steel tubes 0.96 cm i.d. x 2.54 cm o.d. x 7.62 cm long with 0.95 cm pin spacing. Tests were conductd at ambient temperature, 266.4 K (-6.6°C) and 241.4 K (-31.6°C). The results were as follows:

PE-6/Al

Temperature	Density [g/cm³]	Plate dent [cm (in.)]	Detonation pressure [kbar]	Detonation velocity [m/s]
Ambient	1.66	0.28 (0.112)	259	7856
266.4 K (-6.6°C) (20°F)	1.67	0.23 (0.089)	267	8004
241.4 K (-31.6°C) (-25°F)	1.65	0.22 (0.086)	269	7991

The results indicate that PE-6/Al is not affected by low temperatures down to 241 K. Jones (ref 10) reports that a velocity of 7800 to 8000 m/sec was obtained for PE-6/Al with a density of 1.6 g/cm^3. Also reported (ref 5) were values of 7600 m/s and 7900 to 8000 m/s for 1.60 to 1.62 g/cm^3. The critical diameter is under 1.27 cm.

Bullet Impact Test

The bullet impact test could not be conducted on PE-4 and PE-6/Al, due to the small sample size furnished. A modified bullet test was devised at Yuma Proving Ground where 30.48 cm segments of actual hose loaded with PE-6/Al were subjected to various firings (ref 14).

The first phase consisted of suspending a 30.48 cm segment with rope between two frames and using wood backing. Five tests were conducted using .50 caliber ball ammo. The muzzle of the gun was located 21.64 m (71 ft) from the target. In the first phase no effect was evident in the five tests except that each segment burst open upon impact by the ball ammo.

The second phase was a duplicate of the first phase except that .50 caliber tracer ammo was used. In these tests the tracer bullets went through the hose sample without any bursting occurring.

The third phase used steel plate backing and .50 caliber mild steel ball ammo. Four of the tests did not show any effect while the fifth test caused burning in the hose sample.

The fourth phase used steel plate backing with .50 caliber tracer ammo. Three tests showed no effect while three other tests produced burning of the hose samples.

Additional Data

The following PE-6/Al data is made available for information purposes (refs 5 and 15)

Power - Plate dent test - 70% of RDX
Power - Fragmentation - 67% of RDX
Heat of explosion - 6322 kJ kg^{-1} (1511 cal/g)
Volume of gas evolved (NTP) 823 m^3 Mg^{-1}
Viscosity - 700-1500 Pa s ($m^{-1}kg\ s^{-1}$)
Thermal conductivity - 232 x 10^{-3} w $m^{-1}K^{-1}$
Specific heat - 1.095 kJ $kg^{-1}K^{-1}$

EU Propellant

The UK specification for the manufacture of EU Propellant is given in Provisional Specification T.S. 689 (ref 16). Explosives Safety Certificate No. 1533 (ref 17) is used for reference purposes. In this certificate the composition is designated as cordite F547/168 (EU). As a double-base propellant EU Propellant is noted as a propellant with fire risk.

Composition Analysis

The EU propellant was analyzed from the sample from one of the rocket motors. The results of the analysis were as follows:

Basic components[a]	Spec. T.S. 689	Safety cert. no. 1533	ARRADCOM results	Methods
Nitrocellulose[b] %	56.1 ± 1.0	48.0	57.43	AL-P-164-62
Nitroglycerin, %	35.6 ± 1.0	30.5	36.86	MIL-STD-286 208.1.3
Ethyl centralite (carbonate), %	2.4 ± 0.2	2.0	2.59	MIL-STD-286 202.23
Cellulose acetate	5.9 ± 0.3	5.0	3.12	by difference
%	100.0		100.00	

Additives

Basic components[a]	Spec. T.S. 689	Safety cert. no. 1533	ARRADCOM results	Methods
Triacetin (glycerol triacotate), %	14.6 ± 1.8	12.5	17.85	MIL-STD-286 204.1.2
White load, %	2.4 ± 0.6	2.0	1.99	MIL-STD-286 311.2.2
		100.0		
Total volatiles,%	0.6 max		0.069	MIL-STD-286 103.3.3
Wax		0.075		

[a]Calculated on a triacetin, white lead and total volatiles-free basis.
[b]Calculated on a nitrogen content of 12.20 ± 1.0 percent.

The analysis procedures used are correct to ± 1.0%.

Detonation (Blasting Cap) Test

This was conducted in the same procedure as for PE-4 and PE-6/Al. The EU Propellant, weighing 88 g blew a hole in the witness plate when initiated by an M-6 blasting cap.

Unconfined Burning Test

An 88 g sample of EU Propellant placed in a container with sawdust saturated with No. 1 fuel oil. The sample burned with the flame dying out after 1,360 seconds.

Thermal Stability Test

A cylinder of EU Propellant, 3.81 cm in diameter, 5.06 cm in length, and weighing 88.2 g was placed on a vacuum oven at 348 K (75°C) for 48 hours. The length was reduced by 0.8%, the diameter by 0.07%, and the weight by 0.45%. The sample became slightly darker in color and seemed slightly softer since it was harder to measure with the micrometer.

Vacuum Stability Test

Double-base propellants are tested at 363 K (90°C). A 5 g sample of EU propellant in the 363 K (90°C) VST for 40 hours produced 2.28 mL of gas. This is within acceptable limits.

Propellant Heat Test (PATR 3278, Rev 1)

The propellant heat test was conducted at a temperature of 393 K (120°C) (ref 18). This test is used for the acceptance testing of double-base propellants. For EU Propellant the time for the piece of normal methyl violet paper to change to a salmon-pink color was 65 minutes. The red fume value was obtained in 105 minutes. Heating of the samples was continued for more than 300 minutes without any explosion occurring.

For comparison purposes results for other double-base propellants (ref 19) are as follows:

393 K (120°C) Heat Test Values

Double-base propellant	Salmon pink min.	Red fume min.	Explosion min.
EU Propellant	65	105	300+
M7	90	180	300+
M8	55	70	300+
M9	55	75	300+
M13	80	180	300+

Differential Thermal Analysis/Thermogravimetric Analysis

Figure 7 is the DTA/TGA thermogram for EU Propellant which was obtained with a Mettler Thermoanalyzer at a heating rate of 10 K/min in an air atmosphere. In the TGA trace this composition did not undergo any reaction until the onset of weight loss at 378 K (105°C) followed by a very rapid weight loss and ignition at 458 K (185°C) resulting in a 100% weight loss at 523 K (250°C). In the DTA trace the onset of the exotherm was at 453 K (180°C) with the peak and ignition at 458 K (185°C).

Explosion Temperature Test

The explosion temperature data for EU Propellant is plotted in figure 8. The results are listed in table 2. The 5 second explosion temperature for EU Propellant was 497 K (224°C).

The Explosives Safety Certificate No. 1533 states that the ignition temperature for EU Propellant is 448 K (175°C). This is obtained by raising the temperature of a small sample 5 K/min until ignition occurs. The temperature is comparable to the DTA ignition which occurred at 458 K (185°C) at a 10 K/min heating rate.

Electrostatic Sensitivity Test

In the electrostatic sensitivity test, the EU Propellant did not record any fires in 20 consecutive tests at the 0.25 J energy level. The relative humidity was 64% and the ambient temperature was 293 K (20°C).

The Explosives Safety Certificate No. 1533 reports that in the ignition by electric spark test no ignition occurred at 4.5 J (ref 17).

Friction Sensitivity Test

The friction sensitivity test on EU Propellant using the ARRADCOM friction pendulum device produced no reactions in 10 trials with the steel shoe. The relative humidity was 54%.

The Explosives Safety Certificate No. 1533 (ref 17) states that EU Propellant in the friction mallet test reacted (50%) only with a mild steel mallet and the anvil of mild steel.

Impact Sensitivity Test

A full run-down firing curve was conducted on the EU Propellant with the ERL (NOL) impact tester. Also the 50% Bruceton point and the 10% point were determined.

This data is plotted in figure 9. The 10% point was also obtained in the Picatinny Arsenal impact tester. All the data are listed in table 3.

The data obtained using the ERL apparatus indicate that the propellant is more sensitive than Comp B but less sensitive than RDX. However, the 10% firing point value obtained using the Picatinny Arsenal apparatus indicates that the propellant is more sensitive than RDX and PETN, but less sensitive than lead azide.

A figure of insensitiveness value of 20 is reported for EU Propellant (ref 17). Comparison with other FI's indicate that according to the Rotter test the impact sensitivity of EU Propellant falls between PETN and lead azide.

Large Scale Gap Test

The large scale gap test (refs 1, 2, 11) conducted on EU Propellant was performed with approximately 10 samples. The EU Propellant samples were machined from a billet from a disassembled rocket motor. Based on short data the 50% gap for EU Propellant is 2.12 cm (0.835 in.) with a density of 1.53 g/cm^3. Since this is more than 70 cards (each card is 0.0254 cm (0.01 in.) thick) this places EU Propellant in Class A (Military Class 7, UN CLassification 1.1).

For comparison purposes the 50% gap for other explosives according to the large scale gap test are: TNT with 4.65 cm (1.83 in.), Comp B with 6.05 cm (2.38 in.), and RDX with 8.20 cm (3.23 in.)

Closed Bomb Data

The closed bomb test on EU Propellant produced a force of 282,000 ft-lbs/ft with a 0.1 g/cm^3 loading density. This compares to a calculated force value of 305,184 ft-lbs/ft, a flame temperature of 2544.6 K, a ratio of specific heats γ = 1.2443 and a gas volume N = 0.04311 mol/g. The heat of explosion for EU Propellant was determined to be 3085 KJ/kg (737.2 cal/g). The data obtained compares favorably with that for M1 propellant.

S.R. 371C Pyrotechnic Composition (Igniter)

The UK specification for Composition S.R. 371C is given in Specification C.S. S363A (ref 18). For the safety of its manufacture, handling, filling and disposals, Safety Certificate No. 891B (ref 20) describes many of the properties of S.R. 371C. Additional properties and characteristics are reported by Cackett (ref 21). The composition of the pyrotechnic material is as follows:

Component	Limit (%)
Magnesium powder, Grade 3	32.0 ± 1.5
Magnesium powder, Grade 5	10.0 ± 1.5
Acaroid resin, Grade 2, Size 8	8.0 ± 0.8
Potassium nitrate, Grade 1, Size 120	50.0 ± 1.5

This pyrotechnic composition which is used as an igniter mixture was not available in loose, bulk form from the UK. Subsequently, a kilogram batch was blended at ARRADCOM in accordance with the available specifications. The test results obtained in this study were determined from samples of this blended batch.

Vacuum Stability Test

The vacuum stability test (VST) was conducted on a 5 g sample at 343 K (100°C) for 40 hours. The amount of gas evolved was 1.69 mL per 5 g for 40 hours. The value is within acceptable limits.

Differential Thermal Analyses/Thermogravimetric Analysis (DTA/TGA)

Figures 10 and 11 show the DTA/TGA thermogram for igniter composition S.R. 371C in an air and a nitrogen atmosphere, respectively. The results are as follows:

a. DTA (in air)

	Onset		Peak		Remark
Endotherms					
1. 393 K	(120°C)	401 K	(128°C)		KNO_3 x trans
2. 600 K	(327°C)	605 K	(332°C)		KNO_3 M.P.
Exotherms					
1. 661 K	(388°C)	675 K	(402°C)		Minimal
2. 798 K	(525°C)	833 K	(560°C)		Moderate
3. 913 K	(640°C)	923 K	(650°C)		Ignition

b. TGA (in air)

The weight loss of S.R. 371C commenced at 568 K (255°C) which continued until 768 K (455°C) with a weight loss of 12.6%. At 768 K (495°C) S.R. 371C began to gain weight and continued through ignition at 923 K (650°C).

c. DTA (in nitrogen)

	Onset		Endotherms Peak		Remark
1.	395 K	(122°C)	403 K	(130°C)	KNO_3 x trans
2.	593 K	(320°C)	601 K	(328°C)	KNO_3 M.P.
			Exotherms		
1.	653 K	(380°C)	676 K	(380°C)	Moderate
2.	831 K	(558°C)	853 K	(580°C)	Ignition

d. TGA (in nitrogen)

The weight loss of S.R. 371C in nitrogen started approximately at 533 K (260°C) which continued until 778 K (505°C) with a weight loss of 15.8%. At 778 K (505°C) the sample began to gain weight until 853 K (580°C) where mechanical loss of the sample occurred at ignition.

Cachett (ref 21) reports that the effect of continuous heating caused a 0.2% weight loss at 373 K (100°C), 0.5% at 423 K (150°C), and 0.9% at 473 K (200°C). At the final temperature of 503 K (230°C) no change was noted in the appearance of the material.

Explosion Temperature Test

The explosion temperature data are plotted in figure 12. The results are listed in table 2. The 5 second explosion temperature for composition S.R. 371C is 753 K (480°C). Safety Certificate No. 891B (ref 19) reports that the ignition temperature of S.R. 371C is over 673 K (400°C). Cackett (ref 21) reports that the temperature of ignition is 673 K (400°C) and that the material "burns vigorously and explosively."

Electrostatic Sensitivity Test

For S.R. 371C the electrostatic sensitivity test recorded no fires in 20 consecutive tests at the 0.25 joule level. The relative humidity was 64% and the ambient temperature was 293 K (20°C).

The Safety Certificate No. 891B reports that the minimum energy for ignition by spark is 0.24 watt-second (joule). However, Cackett (ref 21) reports a value of 0.045 joule.

Friction Sensitivity Test

The friction sensitivity test using the ARRADCOM friction pendulum device (ref 2, 11) produced no reactions with the steel shoe in 10 tests. The relative humidity during the test was 54%.

The Safety Certificate No. 891B states that for friction sensitiveness Composition S.R. 371C was tested with a boxwood mallet on anvils of concrete, hardwood, and softwood. The only reaction occurred with a concrete anvil where 40% ignitions were reported.

Impact Sensitivity Test

A full firing curve could not be obtained for S.R. 371C using the ERL (NOL) type 12 tool impact tester. At the maximum height of 240 cm only 3 out of 20 trials were fires. The 10% point was 234 cm. The PA 10% point was 40.6 cm (16 in.).

The data indicates that S.R. 371C is less sensitive than TNT on the ERL (NOL) tester. With the PA 10% point the impact sensitivity is comparable to that of Composition C-4.

The Safety Certificate No. 891B and Cackett (ref 20, 21) report that S.R. 371C has a figure of insensitiveness equal to 75. This value indicates that its impact sensitivity is between that of RDX and PETN, which make it moderately sensitive.

Burning Rate Determination

The subject composition was consolidated in brass sleeves 0.594 cm (0.234 in.) i.d.. Total charge weight was 1.200 g in three 0.400 g increments. The consolidation pressure was 36,000 psi with a density of 2.15 g/cm^3. An electric match was used for ignition and photo-cell-counter apparatus was used to obtain the burn time. The average of 5 burn rates was 6.23 sec/in. (2.45 sec/cm).

Typical burn rates for common pyrotechnic compositions are 0.5 sec/in. for 90/10 $BaCrO_4/B$, 0.5 sec/in. for A1A Navy igniter and 3 to 20 sec/in. for $W/BaCrO_4/KClO_4$ delay composition.

Calorimetry Data

The heat of reaction for Composition S.R. 371C was found to be 7026 K J/kg (1679.3 cal/g). Cackett reports that the heat of combustion is 7322 K J/kg (1750 cal/g). The volume of gas evolved NTP is 338 m^3/mg.

CONCLUSIONS

The selected mandatory safety and characterization tests performed on PE-4 explosive, PE-6/Al explosive, EU propellant, and S.R. 371C pyrotechnic composition produced the following information:

Composition Analysis

PE-4 - analysis indicated that the RDX content was about 5.5% less than specification limit.

PE-6/Al - sample analyzed by ARRADCOM indicated that the RDX content was about 6% less than specification limit. Sample tapes from two hoses indicated that RDX was within limits but that the DG29 grease and aluminum were slightly outside limits.

EU Propellant - each of the ingredients varied slightly from the specification limit.

S.R. 371C pyrotechnic composition - analysis not conducted since a batch was blended according to specifications.

Blasting Cap Sensitivity

PE-4, PE-6/Al, and EU Propellant are all cap-sensitive. Test was not conducted on S.R. 371C.

Thermal Characteristics

The results of the thermal tests - unconfined burning, VST, DTA/TGA and explosion temperature - indicate that the thermal sensitivities of:

(a) PE-4 and PE-6/Al compare with those for RDX and Comp B,

(b) EU Propellant compares with those of standard double-base propellants,

(c) S.R. 371C pyrotechnic material compares with that for a 38/62 magnesium/potassium nitrate pyrotechnic composition.

Electrostatic Sensitivity

All the materials passed the electrostatic sensitivity test in which no reactions occurred at the 0.25 J energy level.

Friction Sensitivity

None of the materials tested with the Picatinny Arsenal friction pendulum produced any reactions. However, in the mallet test a 40% reaction occurred with a boxwood mallet and a concrete anvil with the S.R. 371C Composition.

Impact Sensitivity

The impact sensitivity data for PE-4 and PE-6/Al obtained on the ERL (NOL) and Picatinny apparatus indicate that those materials are less sensitive than Comp B and TNT. The figures of insensitiveness obtained on the Rotter impact machine agree with the findings of the study. For EU Propellant the impact data obtained in the ERL (NOL) apparatus indicate that the impact sensitivity of EU Propellant falls between that for RDX and Comp B. However, the 10% point obtained on the Picatinny apparatus indicates that with that tester the sensitivity is between that for lead azide and PETN. The figure of sensitiveness equal to 20 for EU Propellant also indicates that it is more sensitive than PETN. The data for S.R. 371C in this study indicates that this is a fairly insensitive material. The Figure of Insensitiveness equal to 75 for S.R. 371C indicates that this is the same as HMX and slightly below RDX.

Gap Tests

The results of the small scale gap sensitivity tests on PE-4 and PE-6/K indicate that both of these explosives are less shock sensitive than RDX and TNT. The large scale gap sensitivity test conducted with EU Propellant indicates this propellant is less shock sensitive than TNT. A gap test was not conducted on S.R. 371C.

Performance Data

The detonation velocities of PE-4 and PE-6/Al fall between those of Comp B and RDX.

The closed bomb data for EU Propellant was similar to M1 Propellant.

The burn rate and heat of reaction for S.R. 371C compares favorably with other common pyrotechnic compositions.

In view of the above it can be concluded that the UK energetic materials PE-4, E-6/Al, EU Propellant and S.R. 371C pyrotechnic composition, when handled with proper precautions and procedures, do not present any undue safety hazards.

RECOMMENDATION

It is recommended that these materials associated with the Giant Viper be qualified for U.S. military use. Steps should be taken to obtain interim qualification of these materials (ref 2). Most of the test data required is available as a result of this study. Additional data, such as growth and exudation, self-heating (cook-off), and compatibility data will be required for the explosives and propellant. The S.R. 321C will require shock sensitivity and compatibility data.

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Table 1. Test matrix for Giant Viper energetic materials

Test	Explosives PE-4	Explosives PE-6/AI	Propellant EU	Pyrotechnic S.R. 371.C
Composition analysis	X	X	X	X
Blasting cap	X	X	X	
Unconfined burning	X	X	X	
Thermal stability	X	X	X	X
VST	X	X	X	X
DTA/TGA	X	X	X	X
Explosion temperature	X	X	X	X
Electrostatic	X	X	X	X
Friction	X	X	X	X
Impact	X	X	X	X
Small scale gap	X	X		
Large scale gap			X	
Detonation velocity	X	X		
Propellant heat test			X	
Closed bomb			X	
Burn rate				X
Calorimetry data			X	
Modified bullet test		X		

Table 2. Explosion temperature data for Giant Viper energetic materials

Material	Time-to-Explosion Temperature 1 sec K	1 sec °C	5 sec K	5 sec °C	E_a Apparent Activation energy Kcal/mole
PE-4	602	329	532	259	15.53
PE-6/Al	605	332	538	265	15.49
EU Propellant	548	275	497	224	17.22
S.R. 317.C Pyrotechnic	816	543	751	478	30.30
RDX	596	323	523	250	13.69
Comp B	581	308	529	256	18.88
TNT	709	436	623	359	18.54
PETN			501	288	18.12

Table 3. Impact sensitivity test data for Giant Viper energetic materials and other explosives

Material	Apparatus	Method	% point	Height
PE-4	ERL	Bruceton	50%	105.0 ± 0.81 cm
PE-4	ERL	Run-down	50%	104 cm
PE-4	ERL	Run-down	10%	60 cm
PE-4	ERL	10% PA	10%	61 cm
PE-4	PA	10% PA	10%	35.6 cm 14 in.
PE-6/Al	ERL	Bruceton	50%	121.7 ± 2.9 cm
PE-6/Al	ERL	Run-down	50%	122 cm
PE-6/Al	ERL	Run-down	10%	56 cm
PE-6/Al	ERL	10% PA	10%	61 cm
PE-6/Al	PA	10% PA	10%	33.0 cm (13 in.)
EU	ERL	Bruceton	50%	35.7 ± 1.9 cm
EU	ERL	Run-down	50%	41 cm
EU	ERL	Run-down	10%	28 cm
EU	ERL	10% PA	10%	27 cm
EU	PA	10% PA	10%	10.2 cm (4 in.)
S.R. 371.C	ERL	Bruceton	50%	Above max height of tester
S.R. 371.C	ERL	Run-down	15%	240 cm (max height)
S.R. 371.C	ERL	10% PA	10%	234 cm
S.R. 371.C	PA	10% PA	10%	40.6 cm (16 in.)
PETN	ERL	Bruceton	50%	12 ± 0.13
RDX	ERL	Bruceton	50%	24 ± 0.22 cm
Comp B	ERL	Bruceton	50%	60 ± 0.13 cm
TNT	ERL	Bruceton	50%	157 ± 0.10 cm
Lead Azide	PA	10% PA	10%	7.6 cm (3 in.)
PETN	PA	10% PA	10%	12.7 cm (6 in.)
RDX	PA	10% PA	10%	20.3 cm (8 in.)
Comp B	PA	10% PA	10%	35.6 cm (14 in.)
TNT	PA	10% PA	10%	35.6 cm (14 in.)
Comp C-4	PA	10% PA	10%	48.3 cm (19 in.)

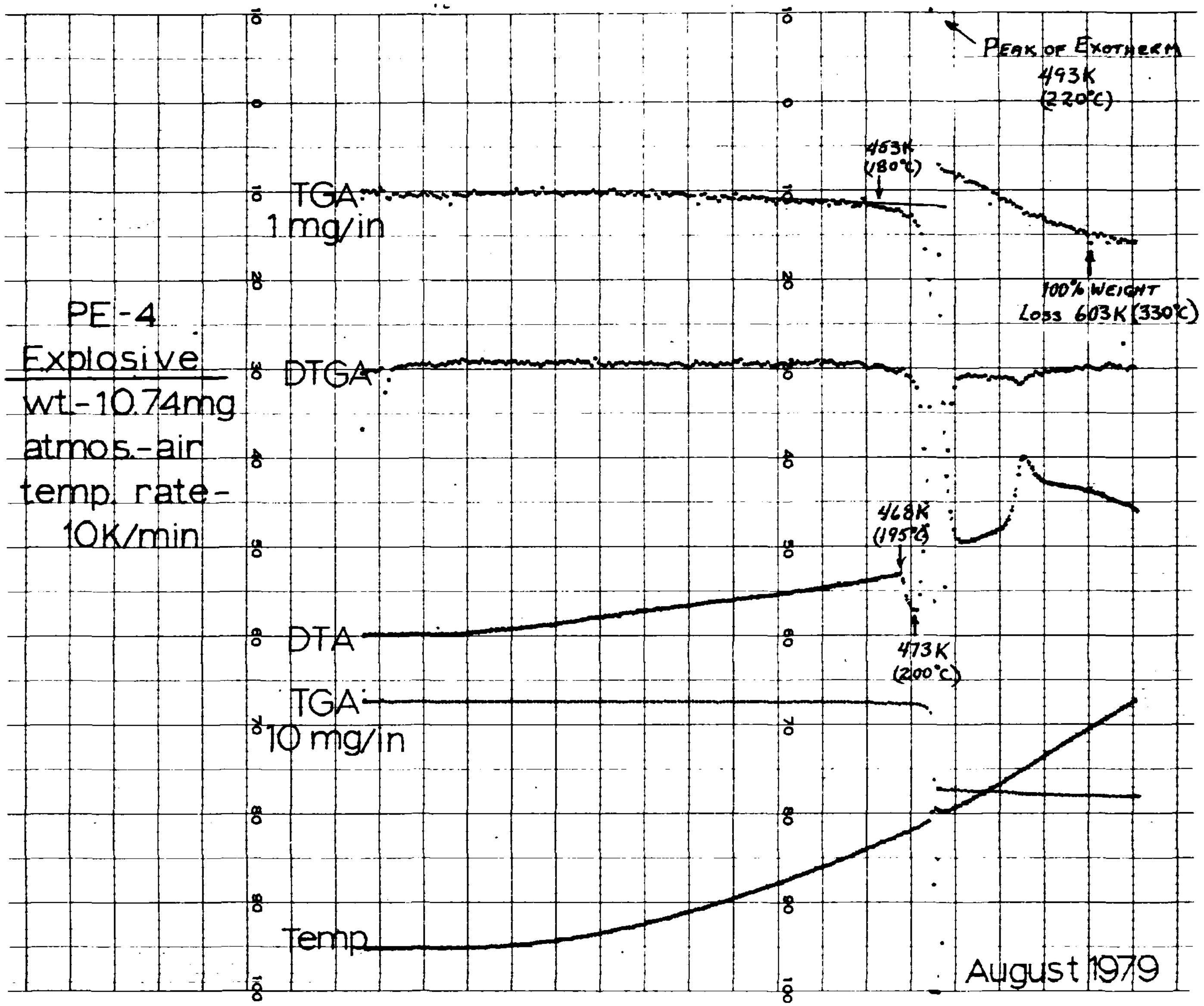

Figure 1. DTA/TGA thermogram of PE-4

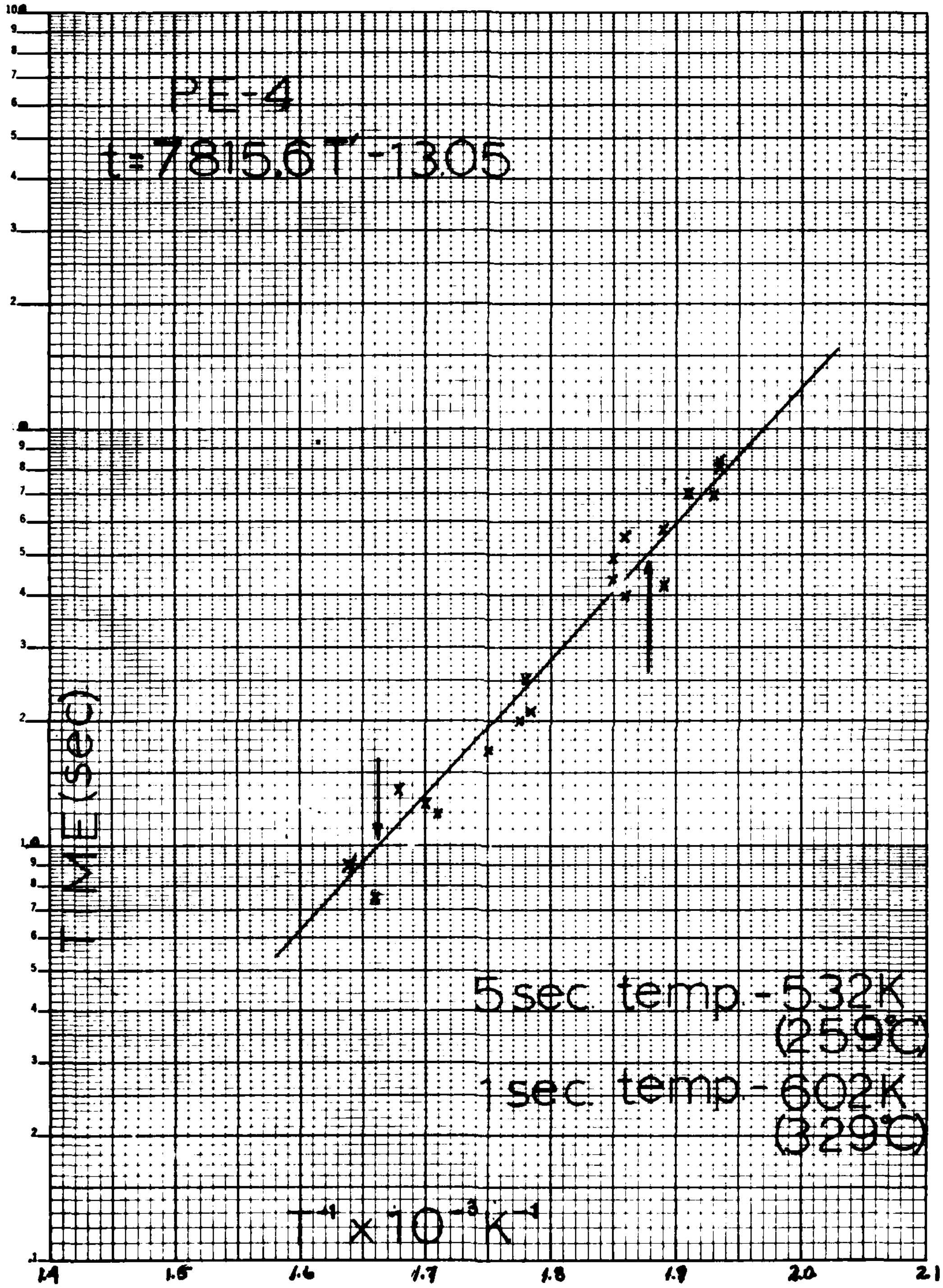

Figure 2. Explosion temperature curve for PE-4 explosive

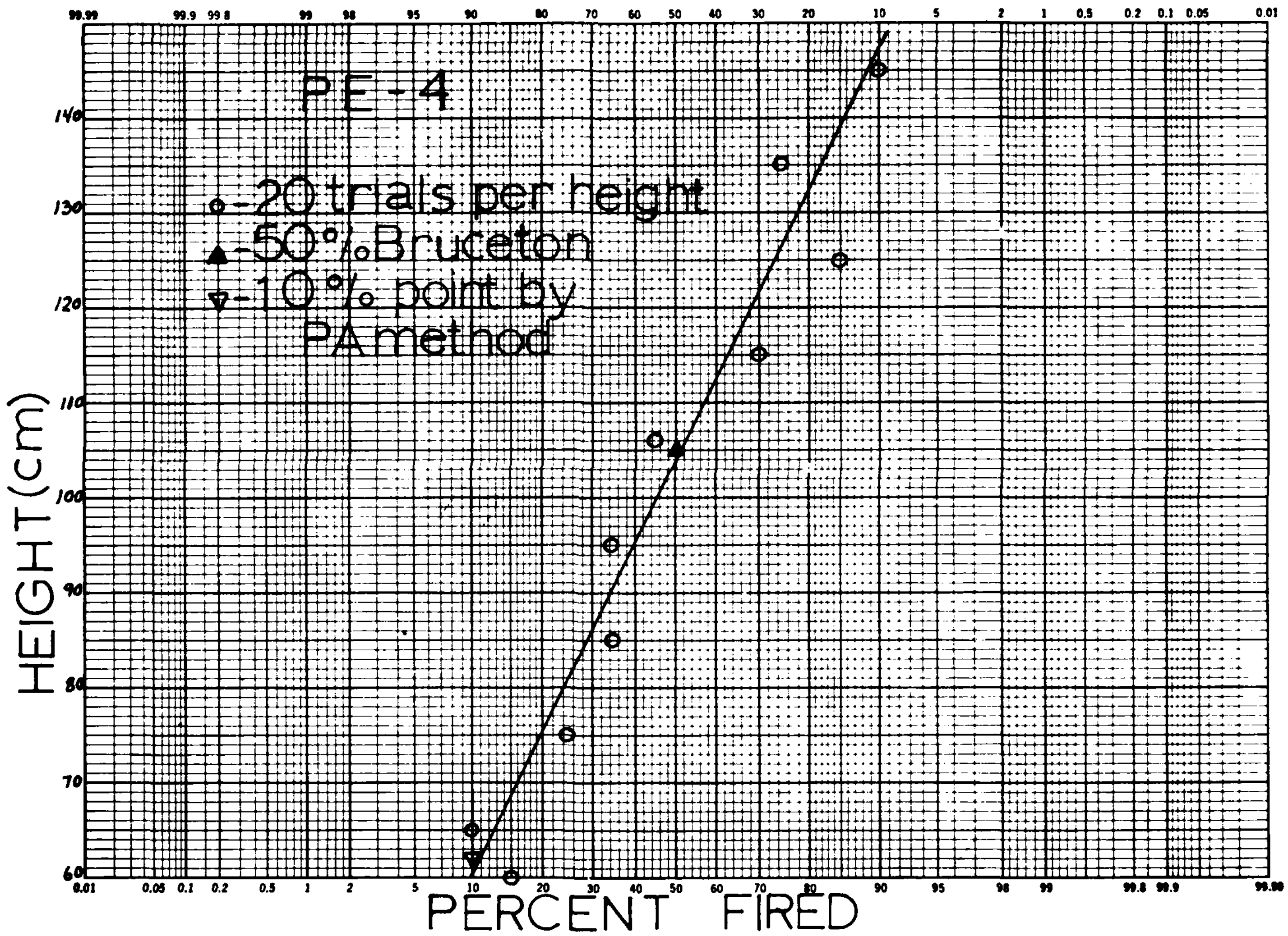

Figure 3. Impact sensitivity curve for PE-4 explosive

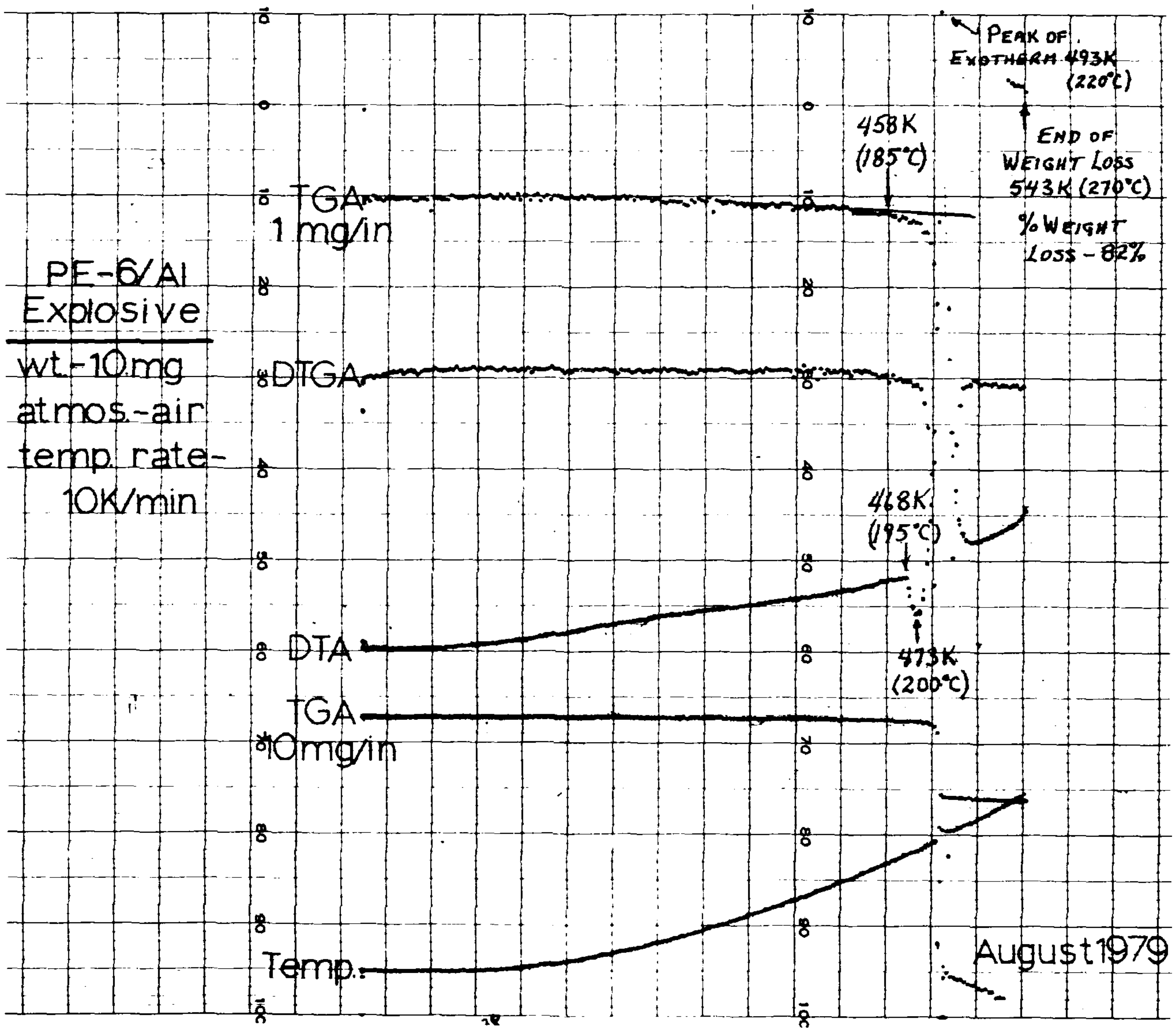

Figure 4. DTA/TGA thermogram for PE-6/Al explosive

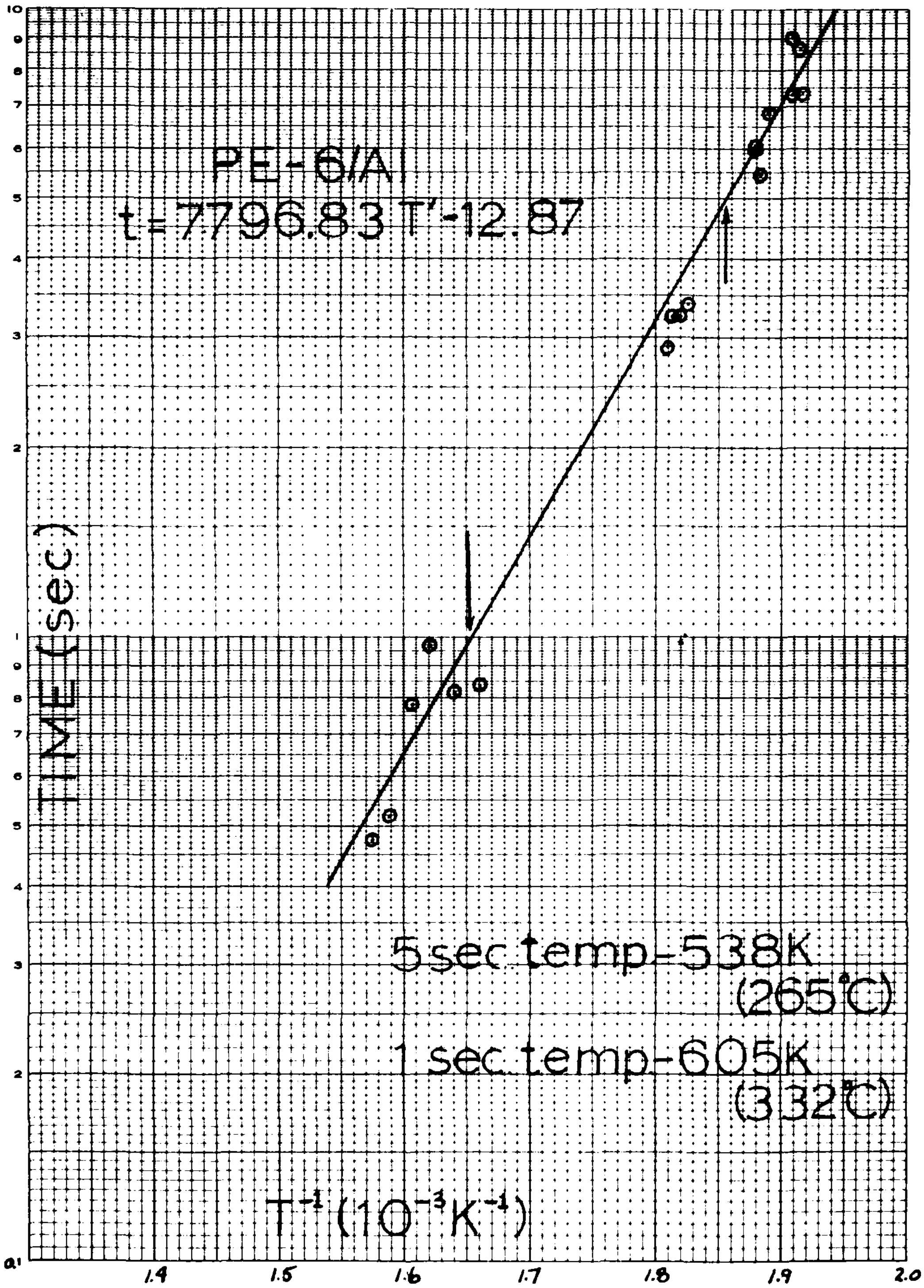

Figure 5. Explosion temperature curve for PE-6/Al explosive

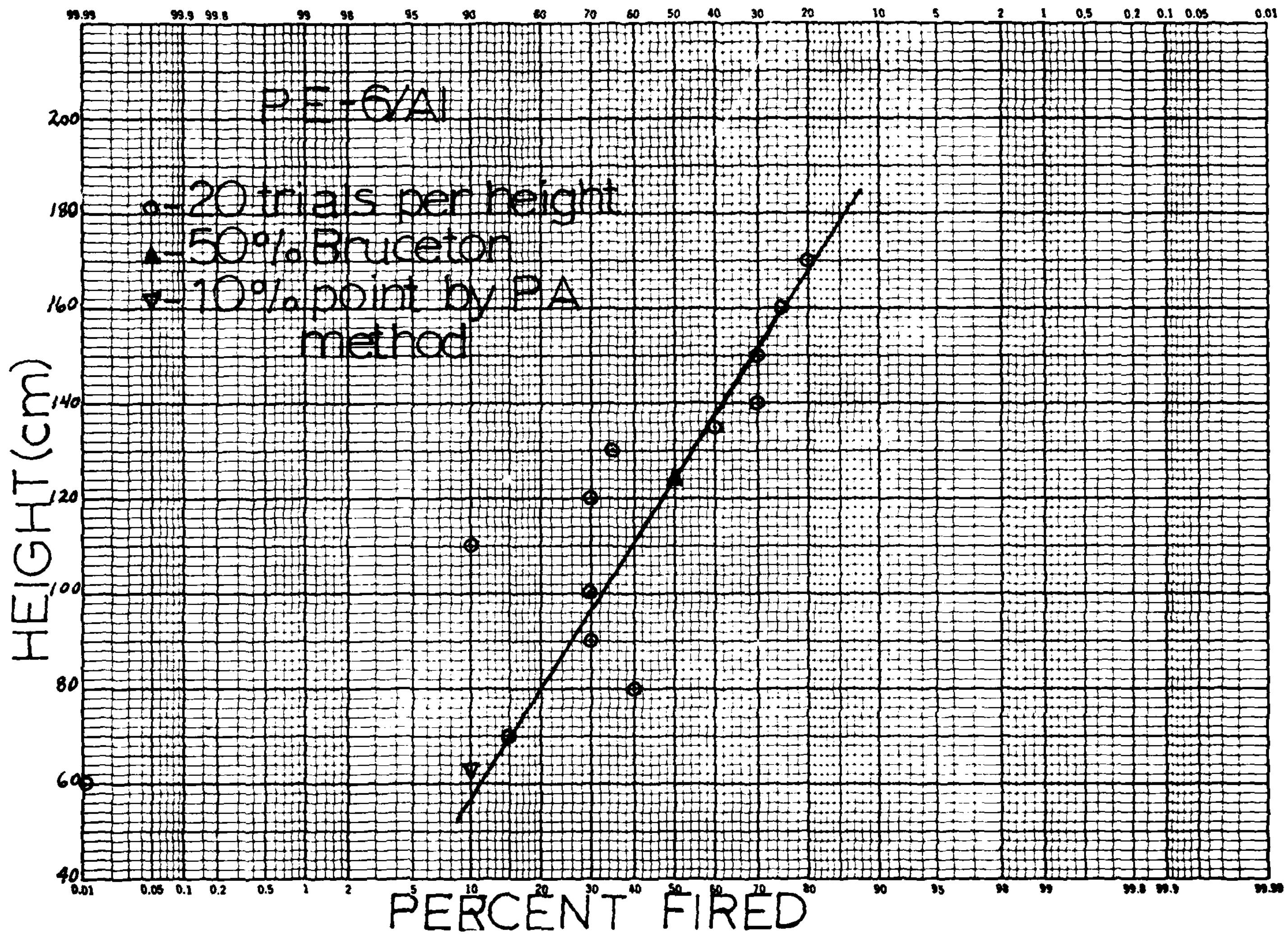

Figure 6. Impact sensitivity curve for PE-6/Al explosive

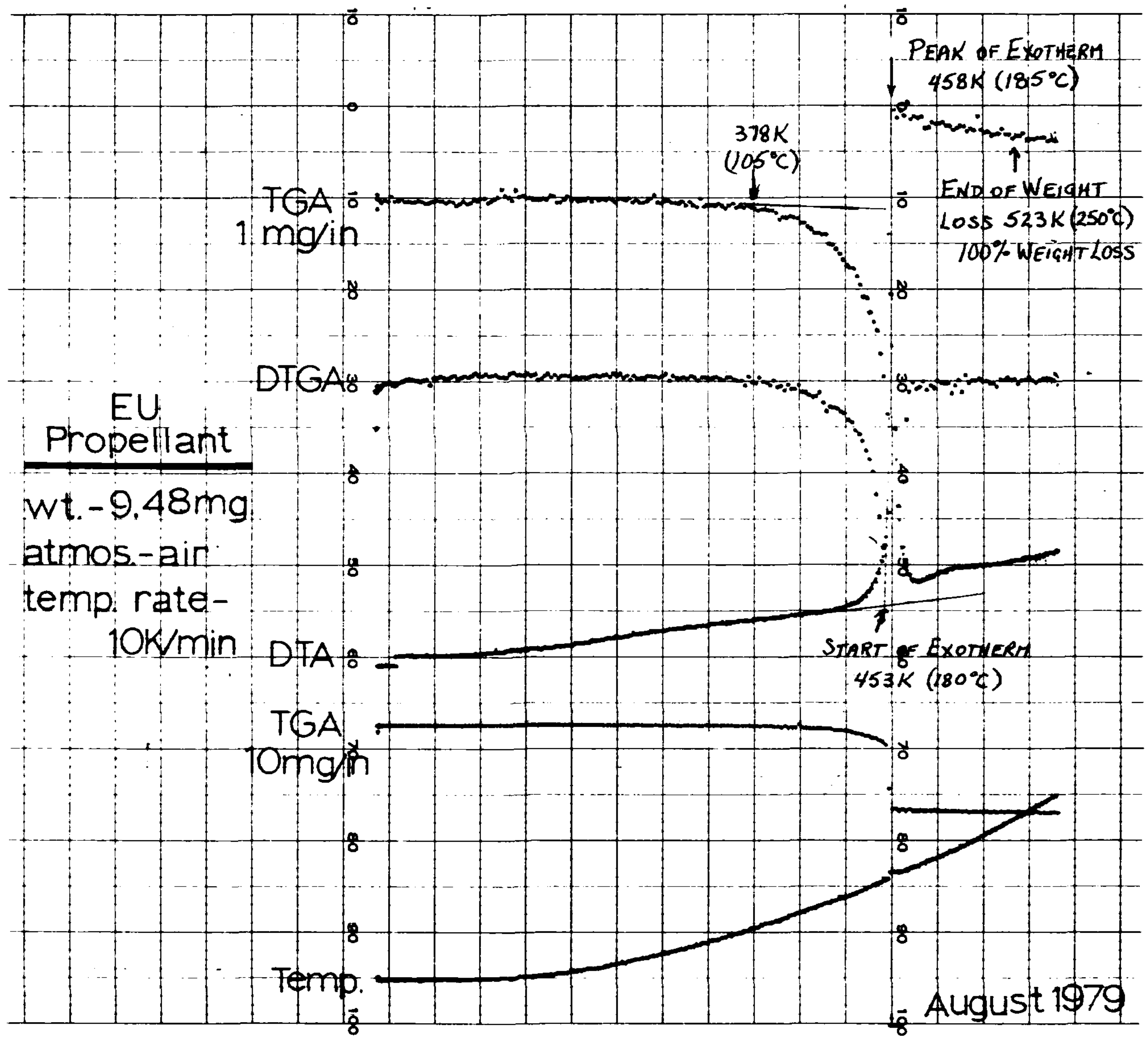

Figure 7. DTA/TGA thermogram for EU propellant

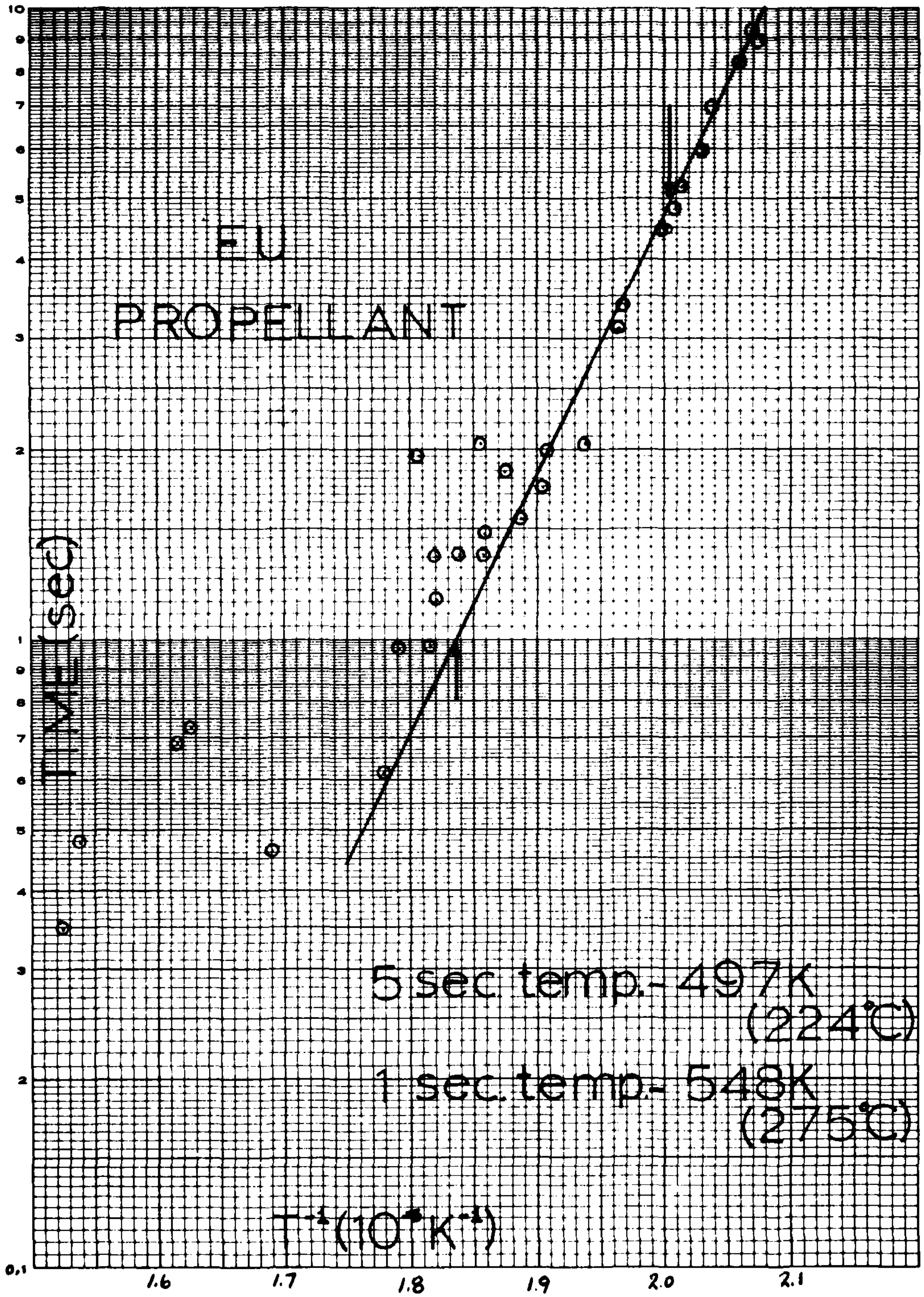

Figure 8. Explosion temperature curve for EU propellant

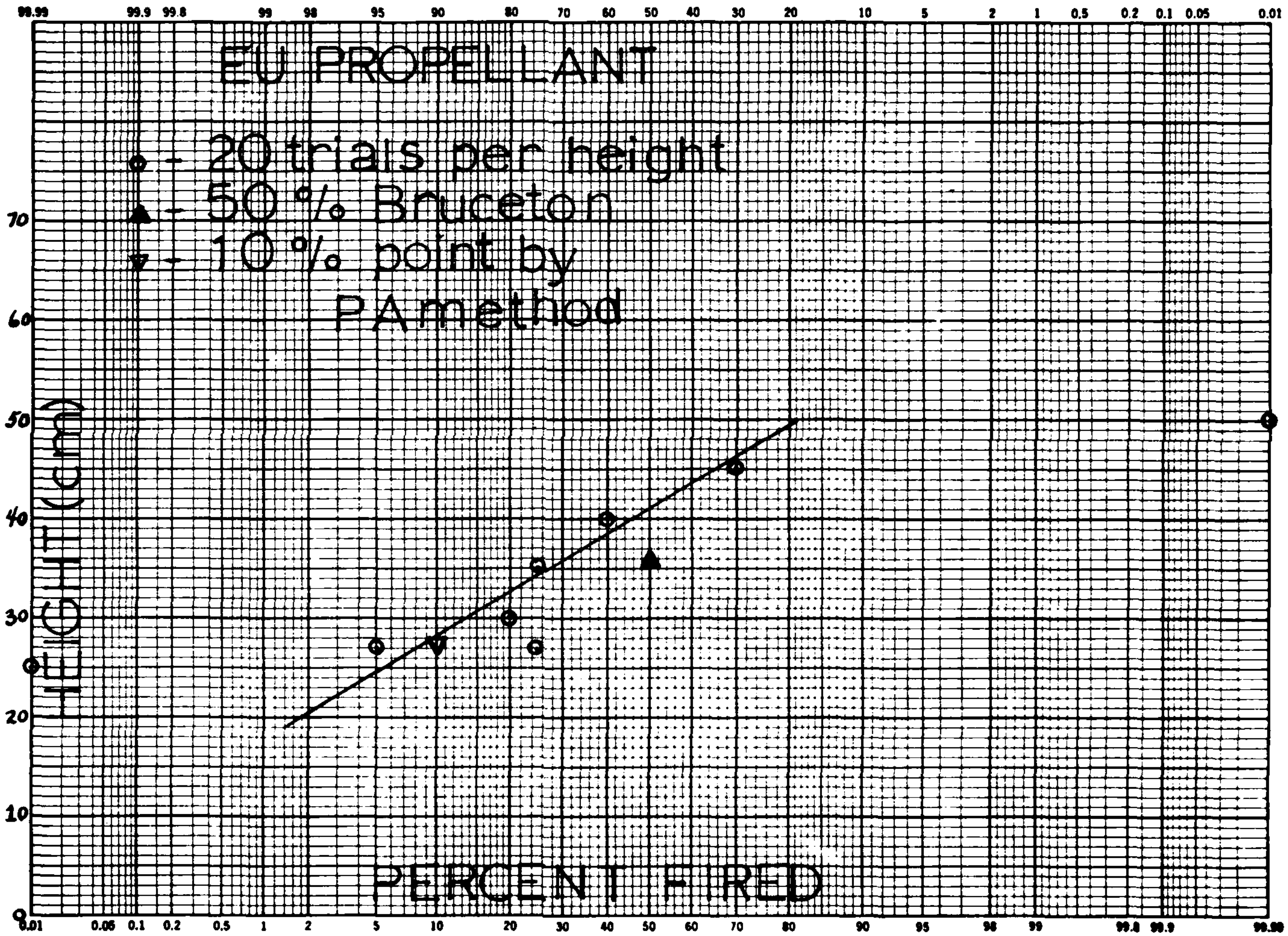

Figure 9. Impact sensitivity curve for EU propellant

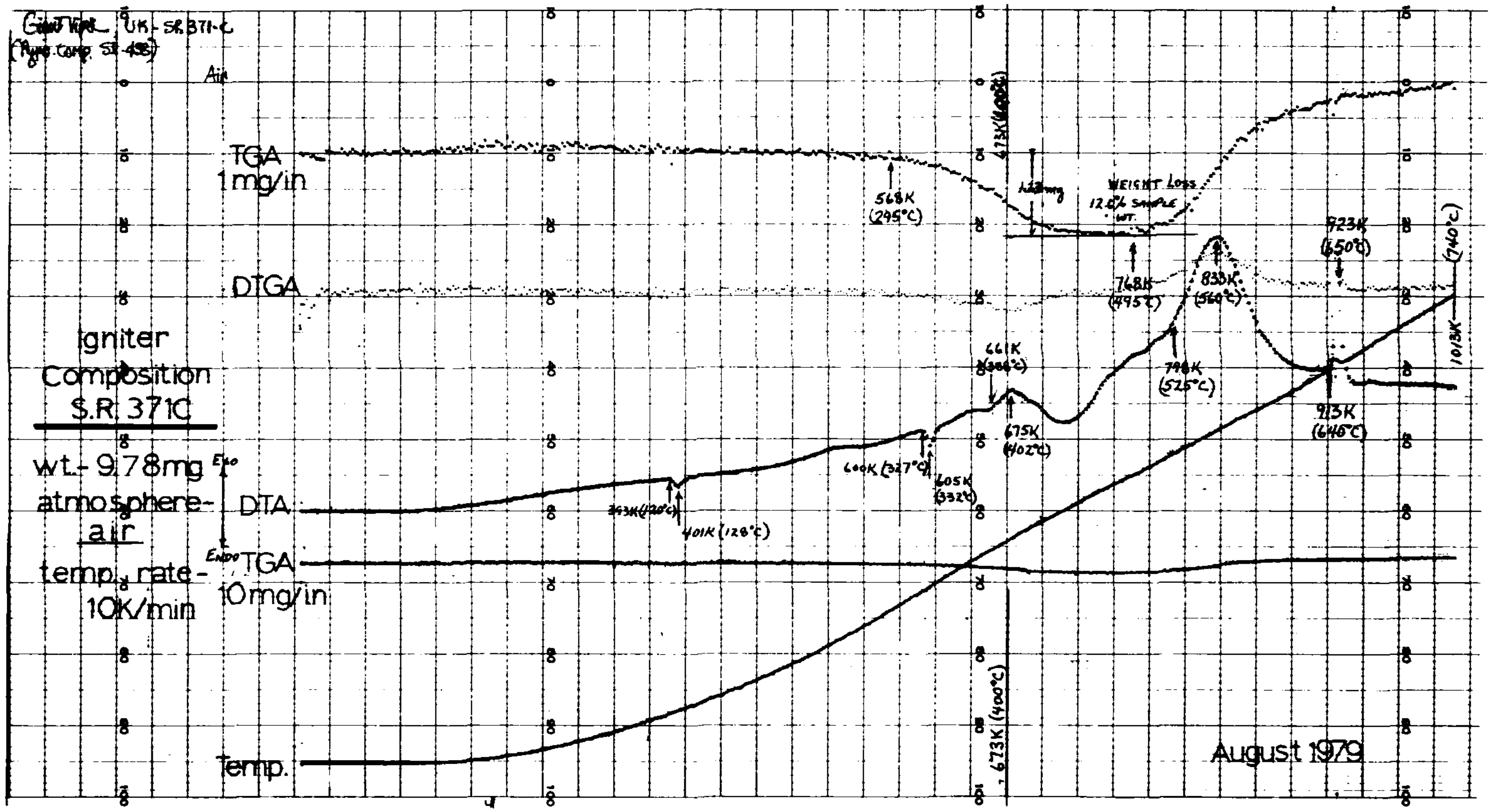

Figure 10. DTA/TGA thermogram (in air) for Composition S.R. 371C

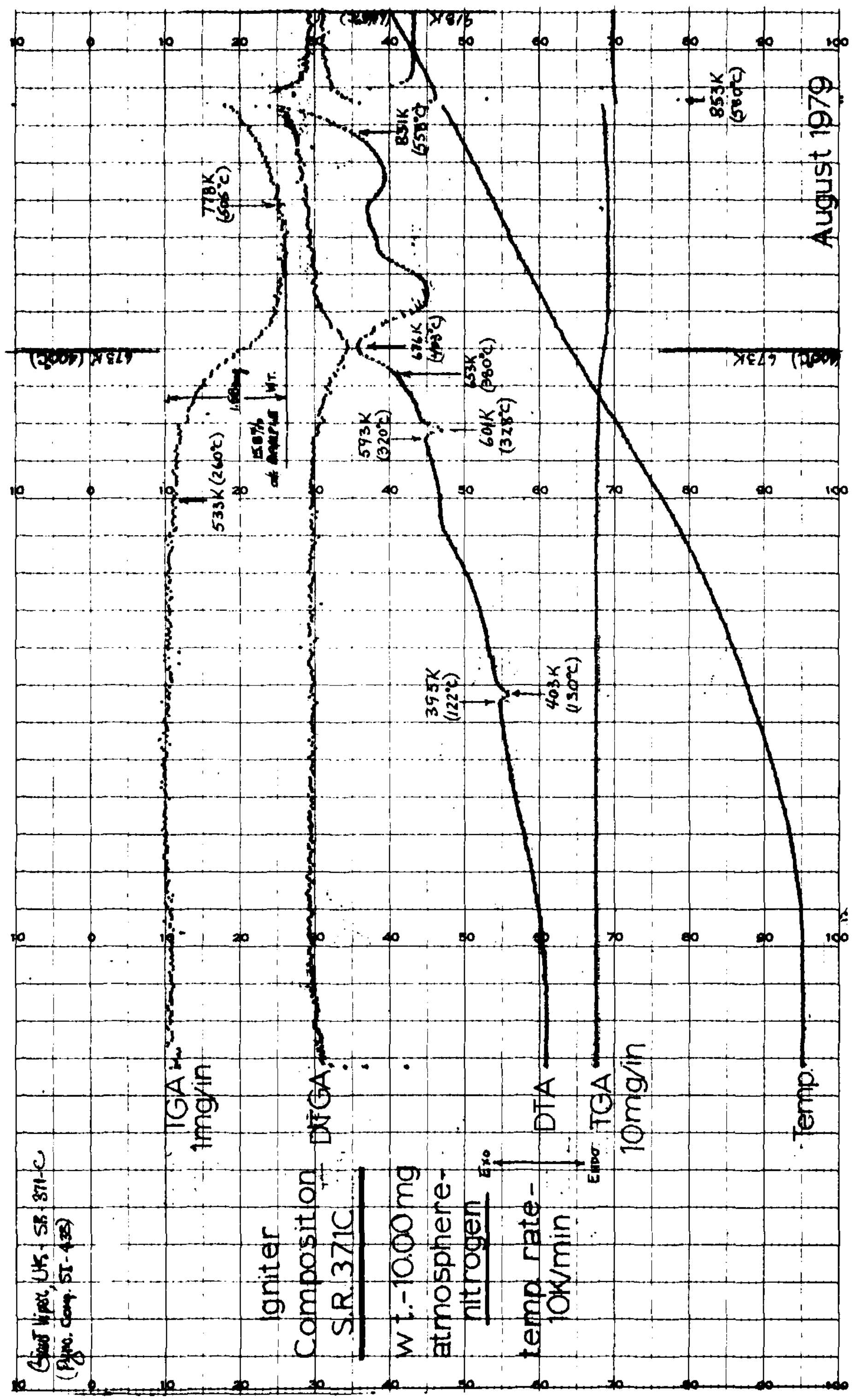

Figure 11. DTA/TGA thermogram (in nitrogen) for Composition S.R. 371C

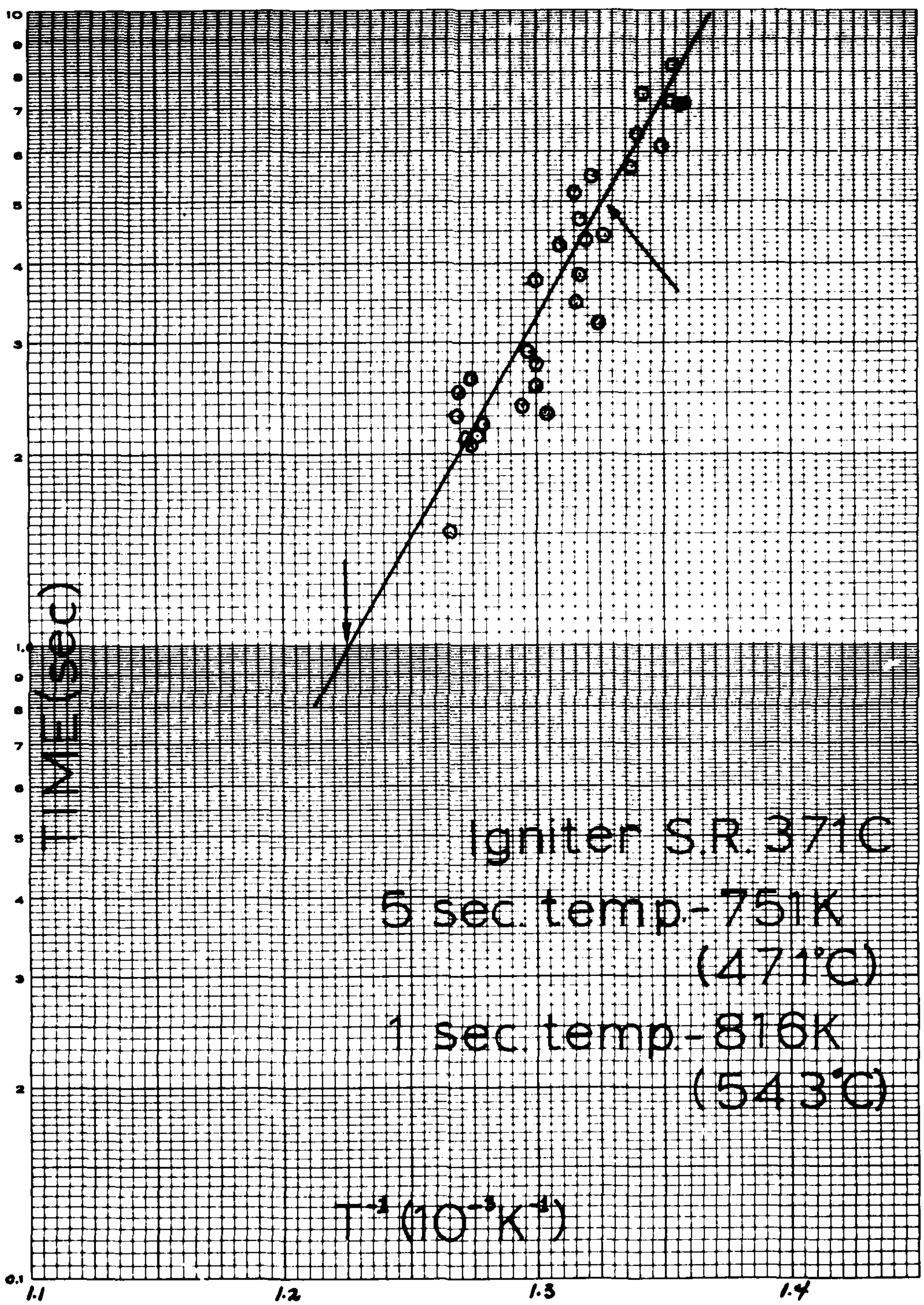

Figure 12. Explosion temperature curve for Composition S.R. 371C

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